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A WIDEBAND AIRBORNE/GROUND
LIGHTNING FLASH LOCATION SYSTEM

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ABSTRACT

This paper presents the design and summary of test results of a new wideband lightning location system. Although this paper emphasizes airborne application, the design and performance of the subject system is identical for both airborne and ground applications. The unique method used for identifying, direction-finding and ranging to a lightning stroke is discussed. The lightning location system is designed to detect severe storms and to identify potentially turbulent weather. A standard video display output shows the location of thunderstorms by displaying the rate of lightning stroke activity. As new lightning strokes are received, the display intensifies on the CRT to show the center of the electrical activity. This provides a display of severe electrical storms similar to the standard radar reflectivity displays. The lightning stroke data is integrated for four minutes. As the number of lightning strokes diminishes, the display decreases in brightness. A standard serial interface provides remote control and monitor capability. For the ground and airborne test programs, the serial channel is used to record all lightning data on a magnetic tape for later retrieval and display. Accurate direction findings is determined by utilizing only the peak pulses of the wideband return stroke waveform. The range estimation from a single station to each lightning stroke uses the differences between the decay of electric and magnetic fields. A single antenna unit consisting of two orthogonal wideband magnetic cross-loops and a short vertical monopole antenna. The system has adequate bandwidth (3 MHz) to detect return stroke pulses for accurate direction finding and ranging. The system has a maximum range of 120 nm radius. Tests on a number of lightning storms at distances to 75 nm indicate the angular resolution is better than $\pm 10^\circ$ and may be in the range of less than 3° with little or no systematic dependence on the number of active thunderstorm cells which are at different angles. The lightning location system is a modular/digital design and may easily be integrated into other digital weather systems. Test results are presented which show the accuracy of the system in locating severe weather. Future plans for advance development of the lightning location system by the Navy are discussed.

+ or - 10 deg

deg

NAVY AIRCRAFT are often required to fly missions in/around adverse weather. The ability of radar to locate severe thunderstorm turbulence is inadequate (1)*. In addition to airborne radar, there are airborne systems specifically designed to detect lightning. However the range accuracy of these lightning detection systems is poor. The range information is based on a so-called ideal lightning stroke amplitude and is determined by assuming a known propagation loss. Furthermore, the lightning data is presented to the pilot serially without adequate correlation with old data already on the CRT. The rate at which lightning data is produced is important to the pilot as a weather hazard prediction. The program reported here was established to provide an alternate and improvement over conventional storm detection systems.

Broadband measurements of the radiation fields (high time resolution) produced by lightning discharges within 120 and as close as 1 show that most lightning waveforms have zero-to-peak rise times of less than five microseconds. Most first and subsequent return stroke fields have several small second peaks or shoulders immediately following the first peak. The large subsidiary peaks (spaced 10-30 microseconds) in first strokes are produced by the effects of branches. Since the propagation speed of a return stroke up a previous leader channel is approximately 200 meters/microsecond, these peak fields are separated by 2 to 6 km. There are many reports in the literature on the electromagnetic characteristics of thunderstorm radiation for example Uman (2-6), Krider (4-6), Taylor (7), Ruhnke (8), Fisher (9), Brantley (10), Herrman (11), and Livingston, (12).

Here, we present a new version of a lightning direction and range finder** (fig. 1), which utilizes the peak of the magnetic radiation fields to provide accurate directions to the channel of individual return strokes. Range to the stroke is estimated by measuring the ratio of the low-frequency magnetic field to the electric field. The performance of the storm warning system during initial test by FAA is presented in a companion paper by W. Lewis in these proceedings. The system operated effectively for discharges as close as a few kilometers and as far away as 200 km. The signals received by a stroke are compared to other strokes within a geographical area. The rate of stroke occurrences are calculated and used to show the intensity of the thunderstorm.

*Numbers in parentheses designate references at end of paper.

**A U.S. Patent Application Serial No. 235, 168 filed February 17, 1981 entitled "Storm Warning Method and Apparatus" is pending.



Fig. 1 - Storm Warning System

APPARATUS

The storm warning system (fig. 2) consists of three units; antenna, display and receiver. The antenna assembly is mounted on either the top or bottom of the aircraft. A low aerodynamic drag shape contains the basic electric and magnetic detectors. The display assembly is a standard raster display. Two size units are available (3 inch and 5 inch) but any video monitor with composite video input and 525 line display may be used. The receiver has been designed for an operation environment defined by MIL-E-5400, CLASS 2. The total weight of the receiver is 14 pounds and head dissipation is 52 watts maximum. The receiver maximum dimensions are 3.25 X 12.37 X 10.25 inches.

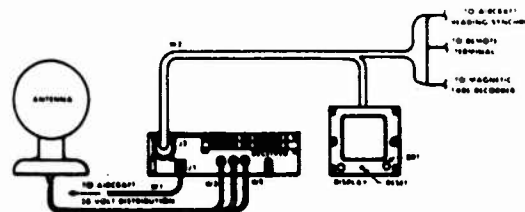


Fig. 2 - Storm Warning System Installation

ANTENNA - The antenna separately receives the electric (E) and magnetic (H) radiation fields produced by lightning. Basically, the magnetic sensors are shielded orthogonal loops with a gap in each shield. The shield around the loop improves the amplitude balance of each loop and minimizes the aircraft structure effects. The magnetic sensor output is proportional to the lightning signal multiplied by the cosine of the angle between the plane of each loop and the discharge. The electric field is sensed by a short vertical monopole. The antenna includes three low pass filters which reject high frequency signals and convert the sensor outputs to 50 ohms.

RECEIVER - The antenna signals (figure 3) go directly to the receiver which has three separate wideband, high gain amplifiers, which provide a system noise figure of 7.5dB. The amplifier gain of 26.5dB was chosen to allow the linear detection of lightning signals between 4 and 200 km. The bandwidth of each amplifier is 1.5 KHz to 3 MHz. The three amplifiers provide signals which are proportional to the time rate of change in

the radiation fields to separate integrators. The output of each integrator (decay constant of 45 microseconds) is proportional to the radiation field waveforms. These signals go directly to separate track and hold circuitry which holds the peak of each pulse in response to a sampling control signal. The control signal is provided each time the electric field value peaks after a rise time less than five microseconds. The resulting voltages (E and orthogonal H fields) are digitized and stored in a first-in-first out (FIFO) memory.

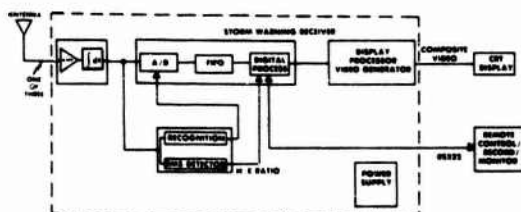


Fig. 3 - Functional Block Diagram

Recognition Circuitry - The output of the electric field amplifier is also connected to recognition circuitry. The recognition circuitry discriminates against interfering signals which are not caused by the lightning return stroke. The recognition circuitry measures two parameters-pulse width and rate of voltage change. The lightning step leader is a narrow-pulse usually on the order of several 100 nanoseconds duration and is ignored by the recognition circuitry. The time rate of change of the electric field is monitored and used to identify a return stroke signal. When the electric field has reached its peak voltage, the sample control signal is generated. After the recognition of the first lightning pulse, an integration control signal which has a duration of one lightning stroke event (approximately one millisecond) is used to interrupt the digital processor.

Low Frequency Detection - The outputs of the integrators are also provided to 1.5 KHz band pass filters which have a narrow bandwidth of 200 Hz. The narrow band signals are separately converted to a signal proportional to true RMS voltage levels. These signals are a measure of the intensity of the electric and magnetic fields. Outputs of the true RMS detector are directly connected to sample and hold circuitry. In response to the integration control signal which is generated at the end of a lightning stroke event, all three outputs are sampled by the digital processor.

Digital Processor - The digital processor digitizes the low frequency data and moves all the sample peak pulse data from the FIFO memory into random access memory (RAM). After the new data is saved, the recognition circuitry is once again allowed to detect new lightning data. The digital processor anal-

yses the sampled peak pulses to determine the general direction to each lightning stroke. First, the low frequency data is used to calculate the absolute ratio of H/E. The magnitude of the magnetic field decreases with the square of the distance from the source while the electrostatic field decreases with the cube of the distance from the source (8). The effects of this relation are clearly shown in figure 4. The amplitudes of the E to H ratio (E/H) at 1.5 KHz frequency are plotted as a function of distance. Although the assumptions of a flat, good conducting ground and a vertical lightning channel are considerable over simplifications, the digital processor algorithm corrects for many of the errors. The test results to date are encouraging as to the value of the H/E ratio to determine range. After the digital processor estimates the range to the stroke the new data is analyzed to determine the lightning stroke rate for the corresponding geographical area. The display is updated to reflect an increase in the lightning flash rate.

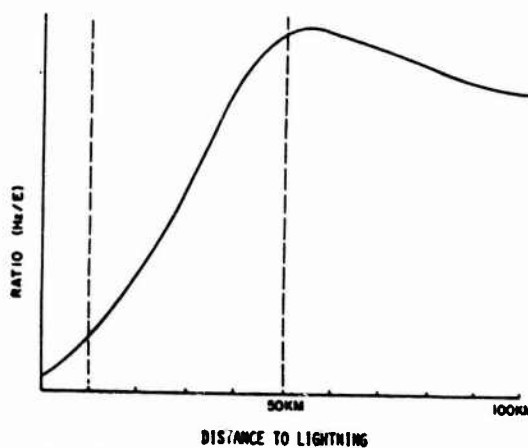


Fig. 4 - Ratio of H/E Versus Distance

TEST RESULTS

During the 1982 storm season, a total of 24 hours of lightning data was collected using the storm warning system which included 6 hours of aircraft turbulence data. National Weather Service (NWS) radar summary data was obtained for the majority of the lightning data. One storm on 28 July 1982 showed extreme turbulence along with a high lightning stroke rate. The lightning stroke rate in general indicated the severity of the storm. The lightning stroke rate appears to go from a low to a high rate in a relatively short time during storm development. The storm of 23 August 1982 represents the typical storm cell which has low lightning stroke rate and likewise, a less severe turbulence than the general storms measured during the 1982 season. The following discussion summarizes test results and shows typical storm warning

display data (see Lewis paper, these proceedings, for comparing lightning activity and turbulence). A detail report of test results may be found in reference 14.

PREFRONTAL SQUALL LINE ON 28 JULY 1982 - A prefrontal squall line of severe thunderstorm cells formed in Pennsylvania and Delaware to the north and west of Atlantic City, New Jersey at 0830 EDT. The storms formed a line about 125 nautical miles long (25 nm wide) moving from 260 deg. at 30 nm/hr. Additional squall lines of thunderstorms formed 50 nm west of the first line.

The NWS Video Integrator and Processor (VIP) contours for 0935 EDT are shown in figure 5 along with an overlay of the storm warning system display. A computer program was used to combine the storm warning data and the NWS VIP contour data. The lightning stroke data (fig. 5) is plotted as a dot for lightning stroke rates less than four strokes per four minutes and circles for lightning strokes greater than four strokes per four minutes. Note storm cell one for the test had a VIP contour level two (L2) approximately 25 nautical miles west of the test site. This cell moved from 270 degrees and, at 1008 EDT, was measured by the doppler radar to be a level four (48-50 dBZ). The doppler data showed possible severe turbulence at approximately 1019 EDT. Later at the end of test period one, the doppler data showed cell 1 to be moderate and the VIP contour level was decreasing.

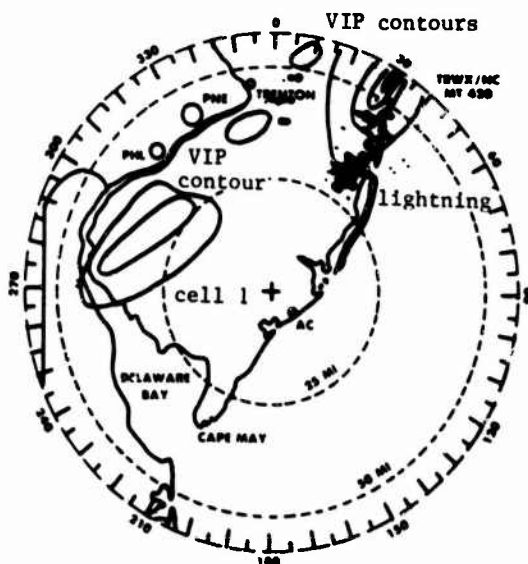


Fig. 5 - Lightning Location vs Radar Reflectivity Contours for 0935 EDT 7/23/82

The storm warning system (SWS) display showed lightning activity to be North East of the FAA Atlantic City, New Jersey, Terminal Facility of Automation and Surveillance Testing (TFAST) site between 25 nm and 50 nm.

The dark areas indicate lightning activity occurring at a rate of more than four strokes per four minutes. Storm cell one to the West of TFAST showed only two dots but the cell to the North was showing extreme lightning activity. This cell was out of range for the doppler radar. Consequently, the aircraft was not flown to the cell. Note the dark lightning cells to be leading the contour plots for the radar data (the cell was moving from West to East). There were moderated levels of lightning activity behind the storm cell. As storm cell one moved North of TFAST, the display indicated extreme lightning activity. This cell was within range of the doppler radar and the aircraft was directed into the storms center.

A new thunderstorm cell formed (cell number two) west of cell one and moved into range of aircraft at 1117 EST. The NWS data indicated a maximum VIP contour level five (L5) and cell height of 38,000 feet. The lightning stroke rate of 139 occurred at the end of test period four. The aircraft did not have clearance to fly into the storm cell and consequently, flew mostly in the peripheral areas. The aircraft did experience a turbulence level of 7.9 (see Lewis, these proceedings, for turbulence scale) during test period five and the pilot reported light hail. The lightning rate continued at a high level during test period five.

Meanwhile, a third storm cell formed due West of the TFAST site at 1135 EDT. The display indicated the new cell to have extreme lightning activity, (fig. 6). The aircraft was vectored to cell three. At approximately 1156 EDT, the doppler radar measured a VIP level of two (39 dBZ) for cell three. Six minutes later, the doppler radar measured a VIP level five (51 dBZ) and the NWS was showing a level six. The storm cell height was now at 50,000 feet. The storm warning system recorded a maximum stroke rate of 88 about five minutes before the aircraft measured a turbulence level of 9.3. The storm warning system was not operated between 1205 to 1227 EDT. At 1227 EDT the lightning stroke rate was 290. The aircraft measured an extreme turbulence level of 13.2 about four minutes earlier. The storm height was now at 55,000 feet. Storm cell three was too severe to continue the test program. The pilot confirmed the lightning activity and measured extreme turbulence at the leading edge of the storm cell.

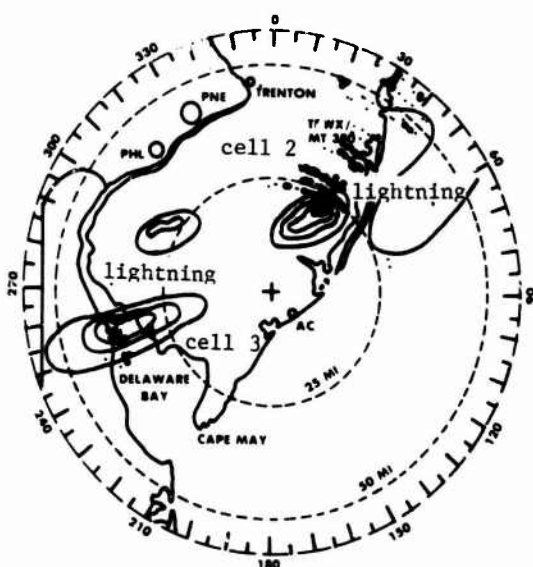


Fig. 6 - Lightning Location vs Radar Reflectivity Contours for 1135 EDT 7/28/82

CONCLUSIONS

The storm warning system was successfully operated as a single ground station during the 1982 storm season and detected, located and recorded over 5,000 lightning strokes. The azimuth angle resolution of the system was measured to be better than ± 10 degrees. The maximum azimuth angle resolution should be in the neighborhood of 2° and will be measured in 1983 storm season. The range accuracy was not easily measured; however, by comparing the thunderstorm cell radar reflectivity contours with lightning stroke data (see examples in figures 5 and 6) the range was estimated to be at least ± 25 percent of the measured range. The performance of the storm warning system to date has proven the feasibility of locating lightning activity.

When comparing the lightning activity with the NWS radar measurements of reflectivity, the lightning activity was not completely confined to the highest reflectivity regions; however, the lightning stroke data was easily associated with the VIP contours for individual storm cells. The lightning activity was found to occur anywhere within the thunderstorm cell. The results have shown that some storm cells (identified by NWS as severe) have high level of measured reflectivity, but produce only moderate turbulence and lightning. However, this lack of lightning activity and turbulence experienced by the test aircraft may not represent the normal convective storms. The data collected during the final Phase of the project should confirm the correlation of turbulence and lightning. As experienced during the 1982 storm season, the results have also shown that convective storms which generate severe turbulence and hail also generated electrical activity.

FUTURE WORK

The calibration of the range accuracy of the storm warning systems will significantly enhance the data obtained on individual storm cells. For the 1983 storm season, the storm warning system will be installed in a Navy A-7 and a FAA Convair-560 aircraft. After calibrating the range capability of the storm warning system airborne measurement of thunderstorms will be recorded using the test methods reported in reference 14. The testing of thunderstorms will no longer be limited to the Atlantic City, New Jersey area. More data will be collected from storm cells in three geographical areas (Oklahoma, New Jersey and Florida). Of particular interest, will be the amount and time of occurrence of hail activity during the convective storm life cycle. In addition, the turbulence factor of each storm cell will be compared with the lightning stroke rate. The final report will be available by 1984.

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